

# SURVEY NOTES

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SPRING 1984

## THE GREAT SALT LAKE INCREMENTAL SAMPLING PROGRAM

By J. WALLACE GWYNN

### INTRODUCTION

EARLY interest in the water characteristics of the Great Salt Lake began with Captain J. C. Fremont during the 1830s and cumulated with G. K. Gilbert's **Lake Bonneville** monograph in 1890 (Monographs of the U.S. Geological Survey, vol. 1, 438 p.) (figure 1). Interest in the lake's multi-brine system has vacillated since then until a formal "incremental sampling program" was initiated by the Utah Geological and Mineral Survey in 1979. The initial program was designed to study the brine density stratification and interface phenomena found deep in the south arm of the lake. Shortly thereafter, the program was expanded to include sampling in the north arm of the lake as well.

The monitoring program consists of determining the lake water's densities and chemical characteristics at one location in each of the north and south arms. Samples at closely spaced vertical intervals are collected on a regular basis every month to six weeks apart. The incremental sampling program differs from the Survey's on-going quarterly brine sampling program in that samples are taken more frequently, at much closer and controlled

vertical intervals, and from permanent towers at known locations. One sampling tower is located in the south arm of the lake, approximately seven miles west of the north end of Antelope Island and the other is in the north arm of the lake, about eight miles east of Gunnison Island.

TABLE IX. *Analyses of Water of Great Salt Lake.*

- I. Sample taken in 1850; analysis by L. D. Gale.
- II. Sample taken in summer of 1869; analysis by O. D. Allen.
- III. Sample taken in August, 1873; analysis by H. Bassett.
- IV. Sample taken in December, 1885; analysis by J. E. Talmage.
- V. Sample taken in August, 1889; analysis by J. E. Talmage.

	I.	II.	III.	IV.	V.
Total solids in 1000 parts of water...	224.2	148.2	136.7	167.2	195.5
Specific gravity .....	1.170	[1.111]	1.102	1.122	1.157

*First arrangement of results; by acids and bases.*

	Parts in 1000 of water.					Per cent. of total solids.				
	I.	II.	III.	IV.	V.	I.	II.	III.	IV.	V.
Chlorine .....	124.5	84.0	73.6	90.7	110.5	55.8	56.0	51.9	54.3	56.5
Sulphuric acid (SO <sub>4</sub> )...	12.4	9.9	8.8	13.1	11.7	5.6	6.6	6.6	7.8	6.0
Sodium .....	85.3	49.6	38.3	58.2	65.3	38.3	33.1	28.5	34.8	33.4
Potassium .....		2.4	9.9	1.9	2.1		1.6	7.4	1.1	1.1
Calcium .....	Trace	.2	.6	.4	.8		.2	.4	.3	.4
Magnesium .....	.6	3.8	3.0	2.9	5.1	.3	2.5	2.2	1.7	2.6
Boric acid .....		Trace								
Phosphoric acid .....		Trace								
Total .....	222.8	149.9	134.2	167.2	195.5	100.0	100.0	100.0	100.0	100.0

<sup>1</sup>The waters of Great Salt Lake. By James E. Talmage. Science, vol. 14, 1889, pp. 444-446.

FIGURE 1

### BACKGROUND

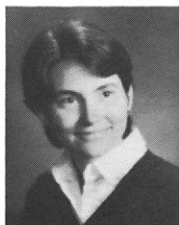
The existence of two superimposed layers of brine in the south arm of the lake, differing in density and other physical and chemical characteristics, was first observed in 1965. When this phenomenon came about, whether it had developed before the construction of the rock-fill Southern Pacific Railroad (S.P.R.R.) causeway in 1960, is not known. The first study by the Survey to characterize the two brine layers and the sharp interface be-

tween them was made in 1976, and the incremental sampling program was begun in 1978. The stratified brine interface phenomenon, as found in the south arm, does not exist in the north arm.

The two towers that have been used for the sampling program were placed at the two locations in the lake by the Amoco Production Company for weather monitoring sta-

Continued on Page 4





## FROM THE DIRECTOR'S DESK

### Great Salt Lake . . . Geologic Hazard and Resource

**T**HIS ISSUE of *Survey Notes* features the UGMS activities associated with the Great Salt Lake. For the last 20 years the UGMS has monitored the lake's chemistry, temperature, layering, salt precipitates, and brines in order to understand the processes that control it and its economic potential to the State. Wally Gwynn's article describes a major program that has centered on the phenomenon of the two brine layers of the southern portion of the lake and the interface between them. Ongoing UGMS studies have attempted to define the resource potential of the lake for sodium chloride (table salt), magnesium metal, chlorine gas, potassium sulfate (fertilizer), sodium sulfate (as an industrial chemical and in making paper), and magnesium chloride (used in producing magnesium metal and as a dust inhibitor). Major trace elements in the lake include lithium, boron and bromine. The initial process in the production of these resources is the concentration of the brine through solar evaporation. For this reason, the initial concentration of the north arm brines (north of the artificial barrier created by the railroad causeway) has made these brines more amenable to production of certain minerals than those of the south area. The rise in lake level has hurt the lake industries by diluting their brines and damaging or flooding their facilities. The change in climate that has caused the lake level's rise also has dramatically decreased the rate at which solar evaporation pond brine can be concentrated.

The rapid rise of the Great Salt

Lake that began in 1982 instigated a program directed toward obtaining a better understanding of lake level fluctuations, defining the flood plain of Great Salt Lake, and providing geologists' input to policies to mitigate damage from lake level fluctuation and related ground water fluctuations. Don Mabey's article summarizes efforts to monitor and predict the level of the lake, explains some of the causes for the lake's fluctuations, and provides a condensed version of the history of the lake for the past 30,000 years.

**T**HE Governor's Conference on Geologic Hazards report of 1983 (UGMS Circular 74) concluded that there are four general types of actions that can be taken to mitigate the harm from geologic hazards be they earthquakes, mudflows, poor ground conditions, or rises in lake levels. When asked about the Great Salt Lake, these same four types of actions came to mind: Avoidance, control, engineering, and preparedness. For such a widespread hazard as Great Salt Lake, a combination of these actions will be most effective.

**Avoidance** — The simplest way to limit the adverse effect of a geologic hazard is to avoid it. The first step in avoiding the hazard is to understand it. UGMS efforts, based on research primarily done by Don Currey of the University of Utah department of geography, have concluded that although the **historic** flood plain of the lake is 4212 feet above sea level, there is ample geologic evidence for recognized risk to 4217 when the lake level reaches a topographically

controlled still stand. Thus, for planning purposes, risk of inundation should be acknowledged to 4217 and decisions to build below this level should be made with the understanding that such facilities can be inundated. For some critical facilities building on the flood plain is a necessary risk. Under such conditions, the risk should be recognized and, control and engineering actions may prove necessary.

**Control** — Some geologic processes can be controlled. Great Salt Lake is so big that control measures are necessarily expensive but may be cost-effective particularly when designed to protect the extensive existing development on the lake's flood plain.

In general, control measures for the lake are of three types: measures to prevent water from reaching the lake, measures to increase evaporation from the lake, and measures to attempt to equalize or alter the levels of the two arms of the lake.

Lake level control alternatives that have been studied by the Department of Natural Resources include: construction of major water storage and irrigation developments on the Bear River; the building of reservoirs for storage and evaporation on the mud flats west of the Bear River Migratory Bird Refuge; diversion of water from the Bear River to the Snake River; and the breaching of the

*Continued on Page 8*

*Barbara Atwood*

# FLUCTUATIONS OF THE LEVEL OF GREAT SALT LAKE

By DON R. MABEY and GENEVIEVE ATWOOD

**I**N September 1982, the Great Salt Lake began a rapid rise that is unprecedented in the historic record. During the following 21 months the lake rose over nine feet causing hundreds of millions of dollars in damage, adversely impacting the mineral extraction industries, disrupting major transportation routes, destroying wildlife management areas and seriously restricting recreational activities on and around the lake. On July 1, 1984, the lake level peaked at 4209.25 feet above sea level before beginning a seasonal decline (see figure 1, page 7). As the lake has risen to higher and higher levels numerous attempts have been made to predict the elevation the lake will reach in the next few months or years. Most predictions have relied entirely on data from the historic record of lake levels and some have used statistical analyses that have little or no foundation in the physical factors that control the lake level. Several actions, most very costly, have been proposed to regulate the lake level or control the spread of the lake (see From the Director's Desk). As the Great Salt Lake has risen, Sevier Lake, Utah's second major terminal lake, has also risen as has the shallow ground-water table in many of the valleys of northwest Utah. Shallow ground water has caused extensive damage in several communities as basements flood and septic systems fail.

The Great Salt Lake receives water from direct precipitation on the lake, inflow from surface streams and direct discharge of ground water into the lake. By far the largest average input, about two-thirds, is from surface streams with the Bear River contributing about 60% of the surface flow. Precipitation is a little less than one-third the input to the lake. The inflow of ground water cannot be measured but has been estimated at 3%. The only water loss from the lake is by

evaporation. The Great Salt Lake drainage basin covers much of northwestern Utah and extends into northeast Nevada, southeast Idaho and southwest Wyoming. All of the precipitation that falls in this basin either returns to the atmosphere by evaporation, or is added to the Great Salt Lake or the ground-water aquifers of the basin.

**T**HE Great Salt Lake goes through an annual cycle. In the winter when evaporation is relatively low, the level of the lake rises until late spring or early summer when inflow to the lake is exceeded by evaporation. The level of the lake then declines until evaporation decreases in the fall. The average annual level change is about one and one-half feet, but varies considerably from this average. The record annual cycle was the 5.2 feet rise in 1982-83. The long term changes in lake level reflect variations in precipitation and evaporation and the development of water resources in the drainage basin. A model by the U.S. Geological Survey for the period of declining lake level ending in 1965 indicated that the effect of development to that date had been to lower the lake level about five feet below what it would have been without any development.

One factor controlling the evaporation of water from the lake is the area of the lake surface, which increases or decreases as the lake elevation rises or falls. Thus an increase in inflow into the lake produces an increase in surface area and the evaporation. The lake level will stabilize when evaporation equals inflow. Plans to control the lake level involve either diverting water from the basin or increasing evaporation. Part of the flow of the Bear River could be diverted into the Snake River drainage near Soda Springs, Idaho. There is general agreement that the Bear River did flow into the Snake River before it was

diverted into the Great Salt Lake drainage by basalt flows about 100,000 years ago. Evaporation could be increased by pumping water from the lake into evaporation ponds or by additional reservoirs on streams flowing into the lake with additional development of the water for irrigation. The extent of the lake can also be controlled by diking.

**T**HE FIRST measurement of the elevation of the Great Salt Lake was by Captain John C. Fremont in September 1843. For three days Fremont's party measured the barometric pressure on the lake shore. He concluded that the elevation of the lake was 4200 feet above sea level. Fremont was back in August 1845 and rode a horse across the bar connecting the south end of Antelope Island to the mainland. His report quoted, by G. K. Gilbert, that "the water no-where reaching above the saddle girths" was later used by Gilbert to determine the lake level at that date.

Although the early Mormon settlers were concerned with lake level fluctuations because it affected their methods of transporting livestock to pasture on the "islands" in the lake, there is no record of attempts to measure the fluctuations. When Gilbert was engaged

*Continued on Page 6*

## IN THIS ISSUE

The Great Salt Lake Incremental . . . . .	1
Sampling Program	
From the Director's Desk . . . . .	2
Fluctuations of the Level of Great. . . . .	3
Salt Lake	
UGMS Staff Changes. . . . .	8
Utah Earthquake Activity . . . . .	9
Conference on Landslides and	
Flooding . . . . .	10
Earthquake Workshop . . . . .	10
Looking Backward . . . . .	11
Great Salt Lake Level . . . . .	12
New Publications. . . . .	12

## THE GREAT SALT LAKE

*Continued from Page 1*

tions during their multi-million dollar search for oil deep beneath the surface of the lake (figure 2).

### THE SOUTH ARM STRATIFIED BRINE/INTERFACE PHENOMENON

#### Upper and Lower Brines

**W**ITHIN that portion of the Great Salt Lake south of the S.P.R.R. causeway, there are two types of brine, one superimposed over the other. The upper brine is typical of that found along the south shore beaches. It is relatively clear, odor free, and readily supports the lake's most abundant resident, the brine shrimp. During the period of the incremental sampling program (1978-83), the density of this upper brine has varied between 1.10 to 1.06 grams per liter, and has dropped to 1.05 during the present high level of the lake.

Beneath the upper brine layer lies the "south arm deep brine" layer which is brown in color, and smells of noxious hydrogen sulfide gas. This layer is of a much greater density than the upper brine and during the 1978-83 period its density ranged from 1.16 to 1.19 grams per liter, but is now reduced to 1.12 to 1.18 due to the high lake level.

The source of the deep brine in the south arm has been established by UGMS researchers to come from the north arm of the lake through deep north to south flow through the causeway itself and through its two fifteen-foot wide culverts and, because of the greater density, settling underneath the lighter-weight upper brine.

#### The Interface

A narrow transition zone, commonly referred to as the interface, separates the upper and deep south arm brines. Here, within a matter of a few inches to a foot or so, dramatic changes take place. First, the density, which above the interface is often quite uniform to the surface, increases abruptly for the few inches to a foot of additional depth. The density then continues to increase, though at a slower rate, to the bottom of the lake. An example of the depth/density profile for the south arm

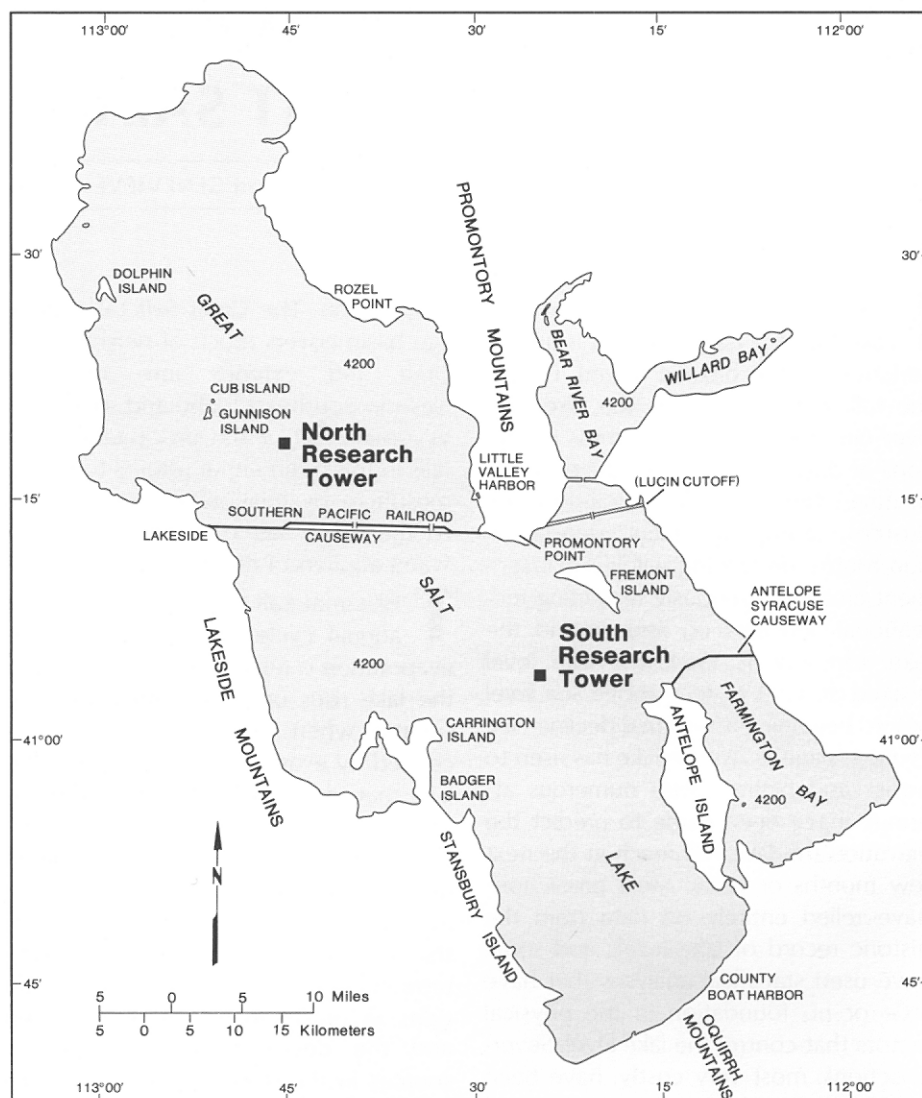


FIGURE 2.

of the lake is shown in figure 3. Second, just below the abrupt change in density, the appearance of the brine changes from clear to light brown due to suspended matter and, third, at and below the interface, the brine smells of hydrogen sulfide gas.

Sampling data suggest that the interface elevation remains relatively stable, fluctuating up and down within about a one-foot range even while the lake's surface elevation fluctuated 7.5 feet. Perhaps the least understood aspect of the deep-shallow brine interface phenomenon is this ability of the interface to remain stable, so sharp and well defined and yet be able to 1) have the deep brine reflect the increasing and decreasing density trends of the shallow south arm brine, and 2) transmit upwards from

the deep brine to the shallow brine the continual volume of inflow received by the deep brine from the north arm.

#### Upper South Arm Dilution and Mixing

Density profiles of the south arm of the lake show that the upper south arm brine becomes homogenized and of uniform density from the surface down to the interface after relatively long periods of stable weather conditions. After storms, however, the combination of dilution from precipitation and mixing by wave action is recorded by a shift of the top portion of the density profile towards a lower density, making a step in the profile. The intensity of the shift is dependent upon the amount of dilution brought about by the storm. The depth component of the step is determined by



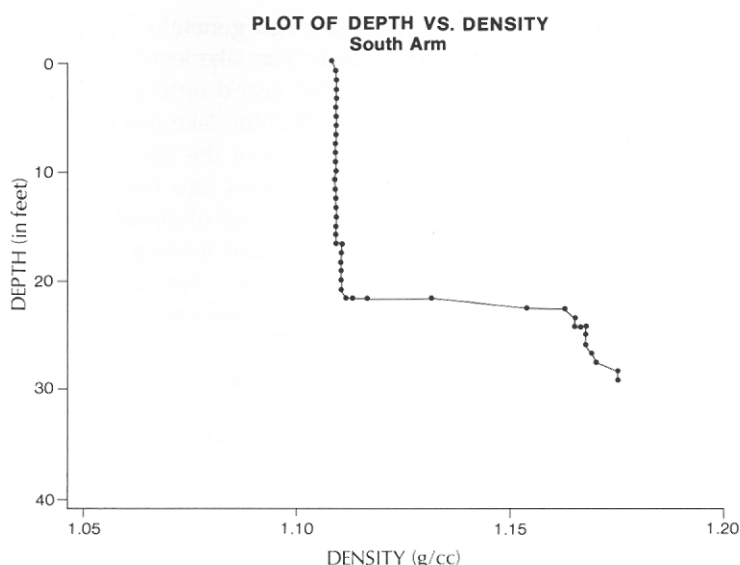


FIGURE 3.

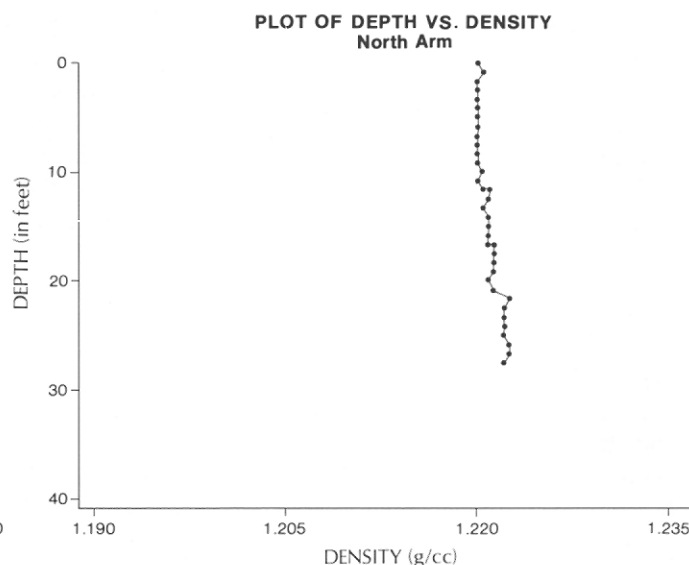


FIGURE 4.

the height of the waves which controls the depth of mixing.

If two or more storms come in succession, their effect on the lake, through dilution and mixing, can be seen by multiple shifts or steps of density through the density profile.

Single or infrequent storms have little effect, if any, in the deep brine portion of the density profile.

Density profiles taken periodically throughout the five-year study period show pronounced shifts in both the upper and lower south arm brine densities in response to the overall dilution or concentration of the lake. These changes are associated with both the short-term, annual rise and fall of the lake, and with long-term lake level trends.

### South Arm Chemistry

Chemical analyses were made on a representative number of the incremental samples taken for any given date and location. The data were obtained to provide information on changes of the lake chemistry both vertically, on a particular date, and with time. The chemistry was analyzed as both weight percent of the brine and as a dry weight percent.

In terms of weight percent of the brine or the total dissolved solids in the brine, the chemistry of the south arm brines was directly proportional to the brine density but was inversely proportional to the lake elevation.

The brine chemistry, in terms of dry weight percent, does not reflect the dilution factor or density of the brine. Rather, it reflects changes in the ratios between the various ions, specifically, Na, K, Mg, Cl and  $\text{SO}_4$ .

The analytical data, on a dry weight basis, for K, Mg, Cl, and  $\text{SO}_4$ , remained relatively constant over the five-year project period, although it fluctuated somewhat from sampling date to sampling date. Sodium (Na), on the other hand, showed a slight continual increase during the same period of time, which probably reflects dissolution of sodium chloride from the floor of the north arm of the lake where it had precipitated between 1979 and 1982. A parallel trend would be expected but was not detected for the chloride ion, but this may be masked by the great percentage of chloride ion present. The sulfate ion also influences the chloride ion's dry weight percent factor.

### THE NORTH ARM BRINE Characteristics

**W**ITHIN the north arm of the Great Salt Lake there is only one brine type, not two as in the south arm. Its density is, however, greater than either of the brine types in the south arm. Its density range has varied between 1.204 to 1.225 during the study period, but has dropped as low as 1.16 during the recent rise in lake level. Until

late 1983, the north arm brine was very turbid, and had a distinct chalky, pink color when seen from the air. Since that time the surface waters appear to be a grey color. Prior to the 1982-84 rise in lake level, the north arm brine has been too salty to allow abundant brine shrimp to live in it.

### Density Differences

Although there is no marked, two-brine system in the north arm, noticeable changes in density occur with depth. These are due mainly to the dissolution of halite from the lake floor and to the precipitation and dissolution of mirabilite.

Between 1977 and 1981, when the level of the lake dropped, the brine became saturated, and much sodium chloride precipitated onto the floor of the north arm. But, from 1981 to the present, the lake has been rising and becoming more dilute; and the north arm brines have, as a result, become undersaturated. Under these conditions, salt is being dissolved from the bottom of the north arm which increases the density of the brine near the bottom of the lake. In density profiles, this increase in density is reflected, usually as a noticeable tail, towards a higher concentration at deeper depths. When there is no salt on the bottom to be dissolved, this increase in density will not be present. As of March 1984, there still ap-

*Continued on Page 10*



**FLUCTUATIONS . . .***Continued from Page 3*

in his study of the lake in the 1870s, he interviewed individuals with information on the past lake levels. His notes from this period include such entries as: "Mr. Lee at the Tithing Office says he forded the Church Island (Antelope Island) in about 1861-63. He lived upon it and passed to and fro many times. He walked in a few inches of water for 3 miles and at the channel got in his ox cart, the water being 2-1/2 feet deep. He thinks the ford was used continuously from 1847 to that time; so did two others present. One old man said he had crossed dry sod in 1847 and that the ford was dry in 1848". Using such recollections, Gilbert constructed a hydrograph of the lake from 1847-75 when the first lake gage was established. Gilbert's hydrograph, which included measured levels from 1875-83, was not tied to a sea level datum. After the establishment of lake level gages, the lake level was measured at monthly intervals for most of the period from 1875 to 1902 but with several breaks in the measurements including one of 13 months in 1884-85. Since 1902, measurements have been made at least monthly. Today continuous measurements are made of the level of both the north and south arm of lake and reported for the first and fifteenth of each month. Although several gages at different locations have been used to measure the lake level since 1875, the hydrograph based on these measurements is probably accurate to within a few tenths of a foot. However, the pre-1875 data based on Gilbert's work which has been approximately referenced to a sea level datum, likely has an uncertainty of at least plus or minus one foot for the annual peak level. This includes the historic peak in 1873, which is often reported to the nearest tenth of a foot.

The 140-year historic period is a very small part of the total history of the Great Salt Lake and earlier lakes in northwestern Utah. The prehistoric record of these lakes is preserved in lake deposits and related land forms rising to elevations 1000 feet above the current lake level. In the last 30 years numerous stud-

ies using new topographic maps, airphotos, new analytical techniques for soil and lake sediment studies and for dating rocks and archaeological material have made major contributions to understanding the Great Salt Lake and earlier lakes. Working with Donald R. Currey of the University of Utah, the UGMS has prepared a publication that reports in a form intended for the general public the geologic and historic evidence of the most significant lake levels over the last 30,000 years. Hopefully, this publication by Donald R. Currey, Genevieve Atwood and Don R. Mabey (**UGMS Map 73**) will contribute to an improved understanding of the Great Salt Lake and aid the development of public policies concerned with the lake.

**A**BOUT 30,000 years ago, following a period of many thousands of years when there was no deep lake in the basin, Lake Bonneville began to rise. About 23,000 years ago, when the lake was about 300 feet deep, the lake rise stalled for several hundred years, and the prominent Stansbury Shoreline was formed. The lake then resumed its rise and by about 16,000 years ago was over 1100 feet deep and overflowed the rim of the Great Basin near Red Rock Pass in

13,500 years ago generally overflowing each season. The lake level then began a decline that lasted until about 11,000 years ago when the lake reached about the current level of the Great Salt Lake. About 10,000 years ago the lake again rose reaching a level of about 4240 feet above sea level and forming the Gilbert Shoreline, and since then the lake has fluctuated below this level, and at times has been nearly dry. For the lake to again rise to the high levels represented by the Provo Shoreline would require major changes in the climate of the Great Salt Lake drainage basin. Models suggest that a lowering of the mean annual temperature of 10 to 15°F accompanied by a substantial increase in precipitation would be required to raise and maintain the lake at this high level.

The historic fluctuations in the level of the Great Salt Lake are controlled primarily by variations in evaporation and precipitation in the drainage basin of the lake with topography of the basin as a minor control factor. However, when the lake level reaches an elevation of about 4217 feet, the Great Salt Lake extends into the Great Salt Lake Desert and combines with bodies of water ponded in topographic depressions there. At this time, the surface area of

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*Since 1902, measurements have been made at least monthly. Today continuous measurements are made of the level of both the north and south arm of lake and reported for the first and fifteenth of each month.*

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southern Idaho. For perhaps 1000 years the lake fluctuated near this level forming the Bonneville Shoreline, the highest in the basin. The outlet of the basin at this level was across unconsolidated sediments, and the catastrophic failure of this dam of sediments about 14,000 years ago released a torrential flood into the Snake River and lowered the lake level about 300 feet. The evidence of this flood is still visible on the Snake River Plain. When the outlet eroded to resistant rock at Red Rock Pass, the lake level stabilized and formed the Provo Shoreline, generally the most prominent of the Lake Bonneville shorelines. The lake remained at this level until about

the lake increases about 40%. With any additional increase in elevation the total area of the lake increases markedly by expanding over the relatively flat desert and thus the lake level tends to stabilize at about this elevation. There is archaeological and geological evidence that suggests that the lake was at or near the 4217-foot level about 300 years ago.

**T**HE MAXIMUM possible level to which the Great Salt Lake can rise is presently controlled by the outlet elevation of about 4780 feet above sea level at Red Rock Pass. However, there is no

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# GREAT SALT LAKE ELEVATION

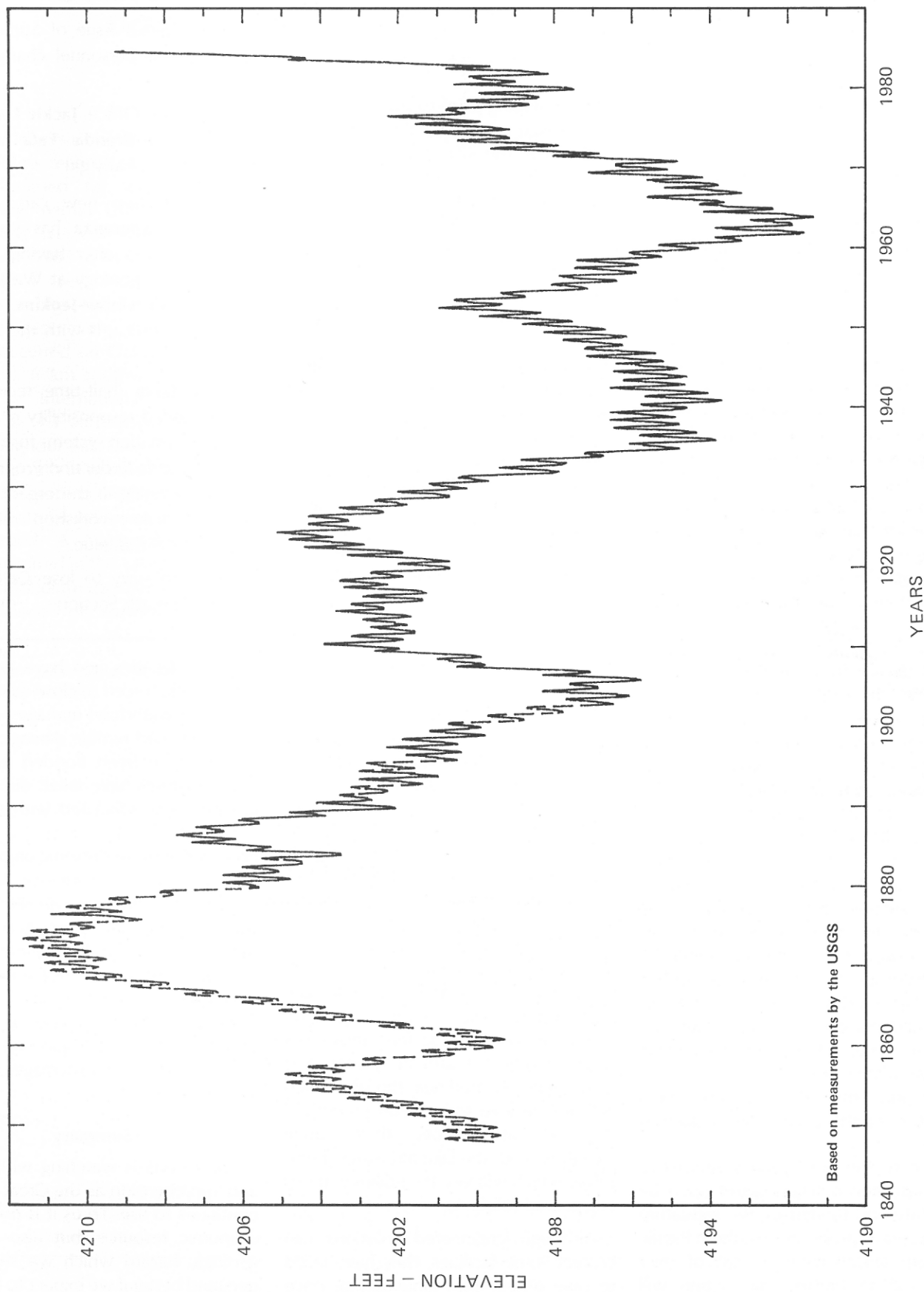


FIGURE 1.



**FLUCTUATIONS ...***Continued from Page 7*

evidence that the climatic changes necessary to raise the lake to anywhere near this level are now underway or likely to develop in the next few thousand years. However, it is reasonable to expect the lake level to periodically rise to about the 4217-foot level under the general climatic conditions that have existed for the last few thousand years. This is about five feet above the historic high in 1873. With this in mind, an argument can be made to define the flood plain of the Great Salt Lake as the area surrounding the lake below 4218 feet.

This year, planners have been asking the UGMS and other entities to predict the 1984 flood level peak of the lake, and to look 2, 5, or 10 years into the future. The UGMS has not attempted to predict these levels but has tried to answer another less frequently asked question: "What is the high level of the lake that is reasonably possible during this current cycle?" Geological and ar-

chaeological evidence indicate that there is no reason to conclude that the lake will not reach the 4217-foot level during a wet cycle such as the one we are in.

In developing plans to limit or mitigate the damage caused by the current rise of the lake, the 4217-foot level should be considered as defining the lake's flood plain. If the state or other governmental entities required developers of land around the lake to recognize this level and accept the risks associated with building below it, the costs to Utah's citizens could be greatly reduced. Local governments even now can choose to incorporate this flood level into their land use plans. Critical facilities such as transportation routes or sewage facilities built on the flood plain should be planned to withstand the flooding or be built with the understanding of the risk that the facility has of being inundated during its projected lifetime. If these measures were taken, the adverse effects of future lake level fluctuations would be minimized. ■

**UGMS STAFF CHANGES**

Since the last issue of *Survey Notes* the following personnel changes have taken place:

In the Sales Office, **Jackie Leadbetter** has replaced **Brenda Tata** who has given birth to a baby girl.

We have two new cartographers: **Patricia H. Speranza** has joined the Editorial Section after having received her degree in geology at Weber State; and **Deborah Ninow-Jenkins**, originally from South Africa, is with the Mapping Section.

**Janine Jarva** (half-time receptionist) has the added responsibility of working on the information systems for the Earthquake Hazards Reduction Program. This includes assisting in the organization of the earthquake workshop mentioned on page 10 of this issue.

We were sorry to lose **Cathy Nanz** from the Hazards Section.

**FROM THE DIRECTOR'S DESK***Continued from Page 2*

Southern Pacific Railroad causeway. Another alternative would be to make water rights and water supply exchanges from the Bear to the Weber River, from the Weber to the Jordan River, from the Jordan to the Sevier River, and/or the Cedar-Rush-Tooele Valley areas. Two other alternative plans include the development of density solar ponds designed for the production of electrical energy; a pump storage/evaporation/power generation project at Puddle Valley west of the lake; and pumping the lake water out onto the West Desert for evaporation and allow the concentrated brines to return into the lake or make them available for the evaporative industries to use.

To date the only control alternative that has been officially acted upon by the State and funded by the legislature is the breach of the the Southern Pacific Railroad causeway at a cost of over three million dollars. This action will partly equalize the levels of the south

and north arms of the lake and will result in a lowering of the south arm by 6-10 inches and a rise of the north arm by 12-20 inches. It will also decrease the magnitude of the annual rise and fall of the south arm of the lake.

**Engineering** — Structures can be designed and constructed to survive geologic events. The rise of the Great Salt Lake is no exception. The railroads and interstate highways are ample proof of this. Other structures may require engineering solutions to withstand the flooding waters. For example, the Salt Lake City International Airport's runways which are about 4220 feet above sea level; sewage treatment plants and storm drains located near the lake which will not be able to function properly if the lake rises above their outfall elevators; and, the lake industries themselves which will lose their dikes without engineered solutions.

Although engineered solutions can protect some facilities, they have failed to save others from inundation: once famous resorts which had been left high

and dry decades ago have now been flooded and forced to close down, recreation and waterfowl management areas have sustained terrible damage, sanitary landfills have been flooded and many septic systems have failed due to rising groundwater associated with the lake's rise.

**Preparedness** — Personal preparedness measures, such as insurance, food storage and sandbagging can reimburse or protect individuals from geologic hazards, such as flooding or earthquakes but such individual measures are not very useful against the rise of the Great Salt Lake where engineering, control, and avoidance techniques are far more attractive in reducing damages than individual preparedness.

**Summary**

The UGMS is watching with interest and apprehension as the Great Salt Lake continues to rise. To us it is not only an economic resource, but also a classic geologic hazard which we should understand better if we expect to live by it compatibly. ■

## UTAH EARTHQUAKE ACTIVITY October 1983 to March 1984

By WILLIAM D. RICHINS<sup>1</sup>

**T**HE University of Utah Seismograph Stations records an 85-station network designed for local earthquake monitoring within Utah, southeastern Idaho, and western Wyoming. During October 1, 1983 to March 31, 1984, 290 earthquakes were located within the Utah region (figs. 1 and 2).

The largest event during this time period occurred on October 8, 1983 at 5:57 a.m., 6 km southwest of the Salt Lake City International Airport. This magnitude 4.3 earthquake was widely felt throughout Salt Lake Valley, as well as to the south in northern Utah County and to the north in the Ogden area. Several small aftershocks were instrumentally recorded. A magnitude 5.2 earthquake occurred in this same area in 1962 causing moderate damage. Other significant aspects of earthquake activity

shown in figures 1 and 2 include (north-south):

- (1) magnitude 3.0 earthquake on December 11, 1983 south of Soda Springs, Idaho;
- (2) a magnitude 4.0 earthquake on November 18, 1983, located near and felt at Snowville on the Idaho-Utah border;
- (3) on-going microseismicity with magnitudes less than 2.1 north of Great Salt Lake along the Idaho-Utah border;
- (4) a cluster of activity 15 km south of Logan during December 22-26, 1983, with magnitudes less than 2.0;
- (5) two magnitude 2.2 earthquakes felt 30 km east of Ogden on March 23, 1984;
- (6) clustered small-earthquake activity in the vicinity of active coal mining SW of Price;
- (7) a magnitude 3.6 earthquake near Cove Fort SW of Richfield on December 9, 1983; and

(8) on-going small earthquake activity scattered throughout a northeast-southwest-trending belt between Richfield and Cedar City.

On October 28, 1983, a magnitude 7.3 earthquake struck central Idaho between Challis and Mackay. This earthquake (labeled as the Borah Peak, Idaho earthquake<sup>2</sup>) resulted in two deaths, approximately 34 km of surface rupture with vertical displacement up to 2.7 m, and \$12.5 million damage. Intensive research in the seismological aspects of this earthquake and implications for possible future earthquakes in Utah are underway at the University of Utah Seismograph Stations.

During late January 1984, the on-line computer facility used for earthquake detection and recording at the University of Utah Seismograph Stations was extensively upgraded to allow a doubling of recording capacity from 64 to 128 data channels. As part of this effort, 24 seismic stations were added to the network in the Yellowstone and central/southeastern Idaho area.

<sup>2</sup>Additional information on earthquake data within Utah and relating to the Borah Peak, Idaho sequence is available by contacting the Univ. of Utah Seismograph Stations, Salt Lake City, UT 84112 (Phone: 801 581-6274).

<sup>1</sup>Senior staff seismologist, University of Utah Seismograph Stations.

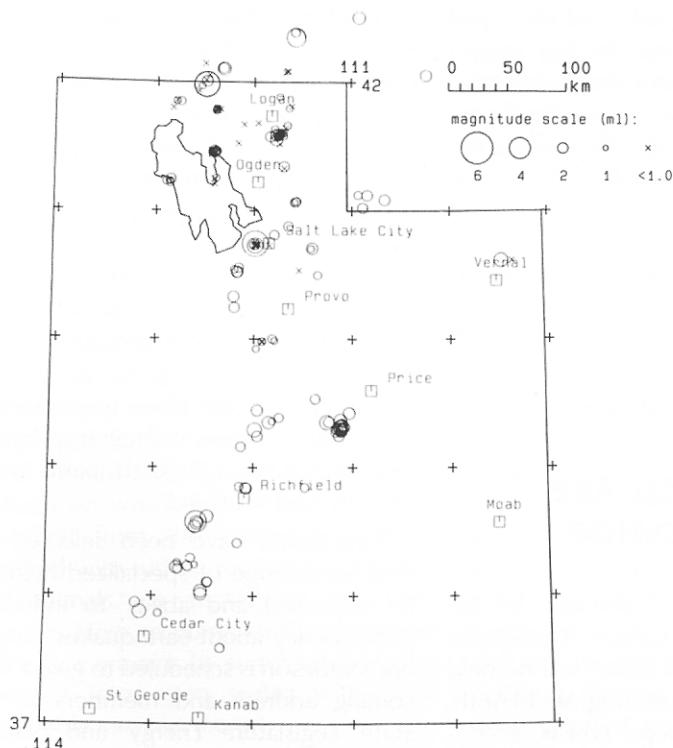


FIGURE 1. Utah earthquakes: October 1 — December 31, 1983

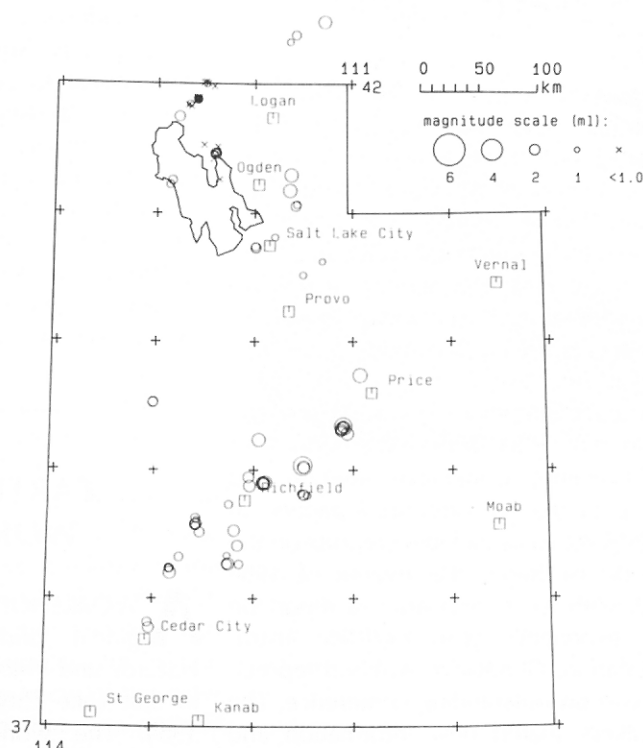


FIGURE 2. Utah earthquakes: January 1 — March 31, 1984



## THE GREAT SALT LAKE

*Continued from Page 5*

pears to be salt on the bottom of the north arm.

During the cold winter months the mineral mirabilite, sodium sulfate decahydrate ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ), precipitates from the cold brine and deposits a thick layer of Glauber's salt on the bottom of the north arm of the lake. As the lake brines warm in the spring, however, the process reverses and the mirabilite dissolves, forming a heavy, sulfate-laden brine at the bottom of the lake. This accumulation of high sulfate brine shows up in density profiles as a tail toward a higher concentration during this time of year. This condition persists until the mirabilite has totally dissolved and the high concentration sulfate brine layer has been thoroughly mixed with the rest of the north arm brine.

### North Arm Dilution and Mixing

Density profiles on the north arm of

the lake during long periods of stable weather conditions, prior to 1983, show that the north arm is well mixed as is shown in figure 4. They also show that the north arm brines react much the same to storms as do the shallow south arm brines.

### North Arm Chemistry

During the latter portion of the project, when sodium chloride was not generally being precipitated, the north arm brine chemistry, in terms of weight percent or the total dissolved solids, behaved much like that of the south arm. The concentration of the ions and of the total dissolved solids were proportional to the density, and inversely proportional to the lake elevation. In the winter months, however, a severe drop in the sulfate ion concentration can be seen due to the precipitation of mirabilite.

In terms of dry weight percent, two changes in the brine chemistry have been observed over time. First, as in the south arm, the percentage of sodium

rises as halite is dissolved from the north arm floor. Second, as the brines are cooled each winter, a dramatic decrease in the sulfate ion content is seen due to the precipitation of mirabilite, with a corresponding rise in chloride ion.

### CONCLUSIONS

**T**HE incremental sampling program reaffirms that the Great Salt Lake is a very complex, dynamic hydrologic system.

With the data available, the stratified brine/interface system in the south arm of the lake as well as phenomena in the north arm are far better understood than they were five years ago. There are, however, many aspects of these phenomena that are not yet fully understood.

A comprehensive report by Paul Sturm on the incremental sampling program is currently in review by the Survey and will be published in the near future. Included within the report will be numerous state-of-the-art computer graphics. ■

## CONFERENCE ON LANDSLIDES AND FLOODING

**A** CONFERENCE on delineation of landslide, flash flood and debris flow hazards in Utah was held at Utah State University on June 14 and 15, 1984. The conference, which was co-sponsored by the Utah Geological and Mineral Survey and several other State and Federal agencies, was attended by about 217 scientists from across the nation.

The conference focused on the events of 1983 with some reports of 1984 events. Genevieve Atwood and Bruce N. Kaliser presented papers on UGMS activities including reports on the Thistle landslide, the events of 1984 and, with M. K. McCarter, a report on the experience with landslide instrumentation. Genevieve Atwood reports: "It was an outstanding conference. The speakers shared new information and ideas. Clearly, the research that was done on the events of 1983-84 has been

effective in developing new instrumentation for monitoring movement of landslides; in defining the characteristics of mudflows, mud floods and landslides; in isolating the key factors that appear to control the transformation of landslides into mudflows; determining key factors that affect the runout distance of mudflows onto the valley floors. It has helped define research needs."

The conference meetings were followed by a one-day field trip along the Wasatch Front. ■

## EARTHQUAKE WORKSHOP

**A** WORKSHOP "Evaluation of Regional and Urban Earthquake Hazards and Risks in Utah" will be held in Salt Lake City on August 14-16th, 1984. The workshop, which is co-sponsored by the Utah Geological and Mineral Survey, U.S. Geological Survey,

University of Utah, Utah Division of Comprehensive Emergency Management and the Federal Emergency Management Agency, will be held in the State Office Building.

Major objectives of the workshop are:

- 1) assessing the present state of knowledge of earthquake hazards in Utah including scientific, engineering, and societal-preparedness components;
- 2) determining what additional scientific, engineering, and societal-response information is needed to implement an earthquake-loss-reduction program in Utah; and
- 3) create action plans to implement an earthquake-loss-reduction program. Approximately 125 participants have been invited to attend.

Participants have been selected for their knowledge of specialized fields to be discussed and ability to influence public policy about earthquakes. Governor Matheson is scheduled to give a welcoming address and members of the State Legislature Energy and Natural Resources Committee will participate in one session of the workshop. ■

# LOOKING BACKWARD

By Wm. LEE STOKES

## Finding Uranium and Oil in the Colorado Plateau

THE study of sandstone uranium deposits began in the Colorado Plateau and constitutes an interesting chapter in economic geology. The difficulty here was getting away from the concept that the ore, since it contains metals, must be hydrothermal. I was a greenhorn geologist hired by the USGS in 1941 and sent out with several parties to help accelerate the production of vanadium, a strategic war commodity. B. S. Butler was our mentor and he set us to mapping joints. This revealed nothing, but when we looked at enough deposits, the fact that the common uranium-vanadium ore bodies known as "rolls" are parallel with depositional features such as cross-bedding, and that ore deposits occupy favorable river "paleochannels," could not be denied. The sedimentological approach gave us something to go by and eventually led to new concepts of the geochemistry and geology of uranium and vanadium ores.

### Looking Backward Fifth article in a continuing series

Early students of uranium deposits believed the Morrison Formation to be marine. In 1914, Frank Hess, writing on the origin of carnotite ores hypothesized that deposition took place in a broad flat basin "occupied by a sea so shallow that steady winds blowing in any direction piled up the waters at the lee end and formed shifting sand bars at many places on which trees which had been washed from the surrounding shores lodged with rushes, reeds, and carcasses of animals." In another of his earlier papers, Hess accounts for the ubiquitous dinosaur remains by surmising that they floated into open water with "considerable meat on them."

Everyone now admits that the uranium minerals were concentrated by sedi-

mentological variations within favorable mostly fluvial formations, but the origin of the metal ions is still a matter of speculation. At first many would have them come from hydrothermal deep-seated sources. Later the idea that they came from the sediments of the containing formations held sway, the term "deposits of lateral secretion" was applied. A variation of this, lately expressed, is that the apparent source was above—namely the marine Mancos Shale. During compaction connate water with mere traces of metallic ions moved down into the Salt Wash Member of the Morrison Formation where they percolated into favorable environments to build up ore bodies.

Many of our past mistakes were put in writing and will endure indefinitely. Many were never written down and are mostly forgotten. But I know of one that must have been repeated to enough college students that it became a part of local geologic lore without having been put into print. I have heard from many of his past students that Dr. F. J. Pack, one of my respected predecessors as head of the Geology Department at the University, emphasized his dim view of the oil possibilities of eastern Utah by saying he would "drink all the oil that would be found there." Strong words that bring forth amazement and disbelief today when Utah has ranked within the top dozen oil producing states.

Why would he make a statement such as this and repeat it so often? He was merely going by the facts he knew about. He knew of the Mexican Hat oil-field that produces from a syncline and was opened up because of oil seeps along the San Juan River. He knew of the great deposits of dead oil in Elaterite Basin, obviously cut into and left high and dry by the general erosion of the Colorado Plateau. He knew of the mile-deep Grand Canyon that cuts entirely through the sedimentary section and into the crystalline basement.

But there was no way for him to know about the wonderful Paradox Basin with widespread source and reservoir rocks in a Pennsylvanian section many times thicker than any seen at the surface. Professor Pack was merely expressing a logical thought based on his feeling that the Colorado River had cut deep enough to drain away any oil fields that might once have been present. ■



A typical vanadium-uranium mine in the Slickrock district, San Miguel County, Colorado. Ore has been taken from the area where the geologist (Stokes) is standing. A smooth roll surface, behind which is barren rock, curves across the channel sandstone with which the roll is parallel.



## NEW PUBLICATIONS

### From UGMS —

- **Map 73, Major levels of Great Salt Lake and Lake Bonneville**, by Donald R. Currey, Genevieve Atwood, and Don R. Mabey, scale 1:750,000, 27" x 46", May 1984, five-colors, map folded in envelope; \$4.50 over-the-counter (see insert for special offer).
- **Bulletin 119, Petroleum Resources of the Paradox Basin, Utah**, April 1984, 162 p., vi, 13 figs., 2 tables, 4 plates folded in envelope; \$15.00 over-the-counter.
- **Special Studies 66, Engineering Geology of Park City, Summit County, Utah**, by Harold E. Gill and William R. Lund, 42 p., vi, 15 figs., 2 tables, appendices; \$5.00 over-the-counter.

### From Atlas Publishing Co. —

- **Map of Lake Bonneville**, by G. K. Gilbert, scale 1: 800,000, reprint of 1890 map (originally published by U.S.G.S. in Monograph I), rolled; available from UGMS or Atlas Publishing Co., 1464-36th Str., Ogden, Utah 84403 for \$8.95 over-the-counter or \$11.95 in tube.

**Orders must be pre-paid.** Postage rates: Orders less than \$10.00, add \$2.00; \$10.00 - \$24.99, add \$4.00; \$25.00 - \$50.00, add \$8.00; \$50.00 - \$100.00, add \$12.00; more than \$100.01, add 12%; add \$1.50 for tube for rolled map (maximum of four map sheets per tube).

### GREAT SALT LAKE LEVEL

Date (1984)	Boat Harbor	Saline
	South Arm	North Arm
	(in feet msl)	(in feet msl)
April 1	4207.35	4204.45
April 15	4207.75	4204.60
May 1	4208.10	4204.80
May 15	4208.35	4204.85
June 1	4208.80	4205.05
June 15	4209.15	4205.30
July 1	4209.25	4205.35
July 15	4209.10	4205.40

Source: U.S. Geological Survey provisional records

### UTAH GEOLOGICAL AND MINERAL SURVEY

#### SURVEY NOTES

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	Governor
Department of Natural Resources .....	Temple A. Reynolds
	Executive Director
Utah Geological and Mineral Survey .....	Genevieve Atwood
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# NEW MAPS

## of Great Salt Lake & Lake Bonneville

**T**HE INCREASED interest at this time in the Great Salt Lake and its rising lake level has inspired the publication of a new map to show the area covered by Great Salt Lake and its predecessor, Lake Bonneville, at various key elevations.

The new map, **Major levels of Great Salt Lake and Lake Bonneville**, is by Donald R. Currey, Professor of Geography at the University of Utah; Genevieve Atwood, Director of the Utah Geological and Mineral Survey and State Geologist, and Don R. Mabey, Senior Geologist and Chief of the Applied Geology Section of the UGMS. The map is in full color, at a scale of 1:750,000. It shows the historic high and low levels as well as the prehistoric Stansbury (20,000 years ago), Bonneville (15,000 years ago), Provo (14,000 years ago) and Gilbert (10,000 years ago) levels. Evidence has been found to show that lakes have existed in the Bonneville basin for at least the last 32,000 years and lakes of various sizes have ex-

isted in western Utah for as much as 15 million years.

This map is available at the UGMS Sales Office for \$4.50, or \$6.50 by mail, prepaid. Add .26¢ for sales tax if purchased in Utah.

More information about the Great Salt Lake is found in **Great Salt Lake, a scientific historical and economic overview**, 1980, edited by J. W. Gwynn. This 400-page book is a compilation of 36 articles on all aspects of the lake, including its geology, pre-history, discovery, recreation facilities, weather patterns, the brine industry, life-forms - you name it! The book has a section of color photos of the lake to show the beauty inherent around a terminal lake in an arid land.

**This book is available from the UGMS Sales Office at the specially reduced price of \$10.00, or \$14.00 by mail, prepaid. Add \$1.58 sales tax if purchased in Utah. As an extra bonus, *The Major Levels of Great Salt and Lake Bonneville* will be included for a total of \$12.50 and \$16.50 by mail, prepaid, sales tax if purchased in Utah is .72¢.**

In addition to these publications, the UGMS sells a reproduction, in full color, of G. K. Gilbert's **Map of Lake Bonneville**, originally published by the U.S. Geological Survey in 1890, (scale 1: 800,000) and recently reprinted by Atlas Publishing Company. This map sells for \$8.95 or \$11.95 by mail, prepaid and comes rolled in a tube. Add .51¢ sales tax if purchased in Utah. The U.S. Geological Survey has also published a topographic map of **Great Salt Lake and Vicinity** (scale 1: 100,000) available for \$3.60 (\$5.60 by mail, prepaid); add .21¢ for sales tax if purchased in Utah.

Title	Price Each *	Sales Tax Each	Qty.	Total Price
Major levels of Great Salt Lake & Lake Bonneville	\$ 6.50	.26¢		
Great Salt Lake — a scientific, historical and economic overview	\$14.00	.58¢		
<b>Above two publications combined . . .</b>	<b>\$16.50</b>	<b>.72¢</b>		
Map of Lake Bonneville, G.S. Gilbert (in tube)	\$11.95	.51¢		
Topographic map of Great Salt Lake and vicinity	\$ 5.60	.21¢		
<b>*Prices include postage — prepayment is required.</b>				<b>TOTAL</b>

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